Using advanced data mining to improve process control and energy management

Cleveland Potash Limited, Boulby Mine

- Initial study improved dryer control system saving 12.5% of dryer fuel use
- Associated cost savings of £47,000/year
- Payback period 5 months
- Identification of additional opportunities
- Applicable across the process industries

NEW PRACTICE CASE STUDY 128

ENERGY EFFICIENCY
BEST PRACTICE PROGRAMME

COMPANY STATEMENT

Historically automatic control of rotary kiln drying plant has proved difficult. The main reasons have been concerned with process complexities such as:

- *the dynamic behaviour of the product and immeasurable changes in its drying properties;*
- *the unreliability of continuous measurement of exit moisture content;*
- *the possibility of large variations in water content of the feed and its unreliable measurement.*

Over the last four years we have developed a comprehensive process monitoring and control system. As a consequence process data is readily available for analysis. Hidden within this data is knowledge about operational performance. This study has introduced techniques involved in data mining and presented new opportunities to improve insight and exploit understanding from the data. Models developed using rule-induction were understandable and easily integrated as rule-based models into our SCADA/PLC systems. Thus a cost-effective control scheme was successfully developed with increased confidence.

The approach adopted for the implementation of the models can be replicated on other plant and the conclusions reached can be considered general. There is scope to apply these techniques more widely and in doing so develop intuitive rules from data that can be used for model-based control, monitoring and optimisation.

Simon Lambert
Instrument/Electrical Engineer, Cleveland Potash Ltd

CLEVELAND POTASH LIMITED

Cleveland Potash Limited (CPL) is part of the Anglo American group, one of the world's largest mining companies. CPL operates the UK's only potash mine at Boulby, 10 miles north of Whitby on the North Yorkshire coast. Ore is mined from 1,100 metres underground, making Boulby the deepest mine in Europe. At the surface the ore is refined to produce around 1 million tonnes per year of high purity potash (potassium chloride) used mainly in the manufacture of fertilizers.

Operations at the site, both underground and on the surface, are complex and energy intensive. The annual cost of electricity is £5.1 million for 145 GWh per year. Fuel oil is used to raise steam and to fire rotary dryers, amounting to 18,500 tonnes per year at a cost of £1.7 million per year.

NPCS 128, this version published 02/02

BACKGROUND

The Clevland Potash mining site

BACKGROUND

The Cleveland Potash Limited (CPL) site at Boulby near Loftus in Cleveland is the UK's only potash mining and mineral processing facility. The site is large and complex, with ore mined some 1100m below ground, raised and then refined to produce potassium chloride (KCl) for use as fertiliser.

In the refinery, ore is conveyed, crushed in rod and ball mills and the potash separated from the unwanted minerals (clay and salt) by froth floatation and crystallisation on a continuous basis.

Three oil-fired rotary dryers are used to produce a dry powder, which is then transformed into either compacted or granulated product. These dryers consume significant quantities of energy as fuel to provide heat for drying and electricity for the associated fans and pumps. Other, above ground, process equipment on the site includes oil-fired boilers, a refrigeration system (for crystallisation), air compressors, large pumps, centrifuges and agitators, all large energy consumers.

Mineral processing is often associated with high energy requirements and CPL is a member of the Major Energy Users Council (MEUC). During normal operation the electrical demand is 25 MW and the average heat demand 38 MWth, with annual costs of £6.1 million and £1.5 million respectively. Heavy fuel oil is used to raise steam and to fire the rotary dryers (there is currently no natural gas supply to the site).

BACKGROUND

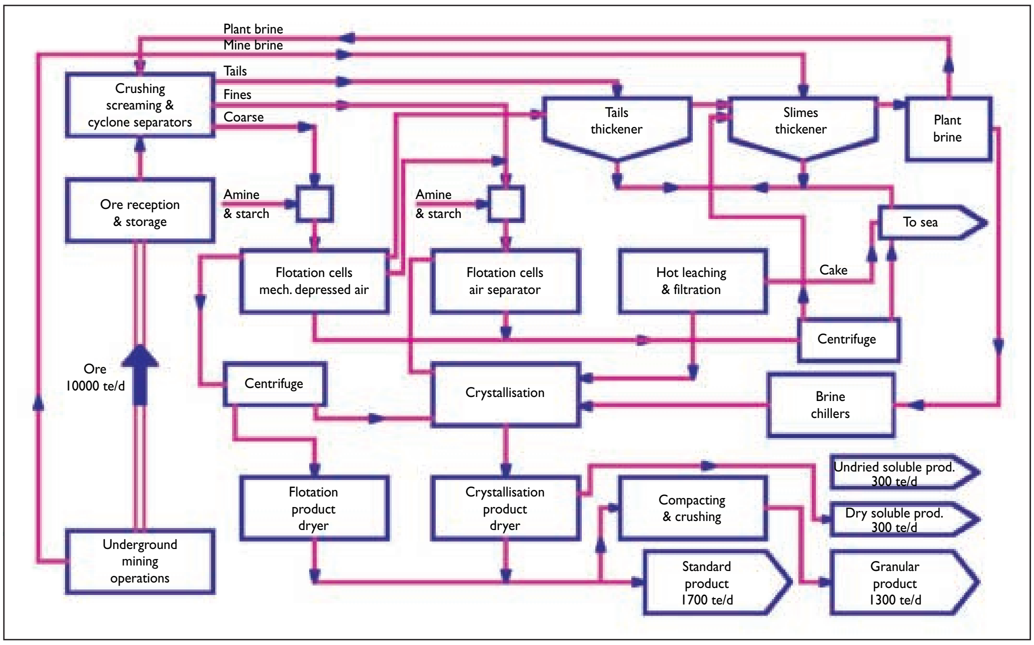


Fig 1 - Process block diagram - Cleveland Potash, Boulby

As with any energy intensive process there is always scope for energy savings. However, because of the complexity of the process, potential improvements may not readily be recognised or, if identified, there may be many barriers to their implementation which arise from fear of adverse effects such as inconsistent product quality, increased complexity, increased maintenance, etc.

The advent of SCADA/PLC systems now enables sites such as CPL to amass large quantities of operating data. Hidden within this data is knowledge about performance which, if extracted, could help identify opportunities for process improvements. Until now the problem has been in analysing the data. However, a range of computational techniques known as data mining is now available with the ability to identify hidden patterns, turning information overload into useful knowledge.

Following the successful adaptation of these techniques to the analysis of process data with Future Practice support from the EEBPP (R&D Profile 67) CPL decided to apply the technology to identify possible process improvements and energy savings at the Boulby site. This is the first commercial application of these data mining techniques to save energy in the process sector.

The objectives were to determine how data mining techniques, especially rule induction (see page 6), can be applied to improve process control and operation, and then to demonstrate how improved control strategies evolving from these techniques can be successfully implemented to achieve energy savings.

The project was monitored independently by Thermal Developments Ltd. Tel: 01740 621614.

Data mining software was supplied by Attar Software Limited. Tel: 01942 608844.

Data mining expertise and training was provided by Knowledge Process Software. Tel: 0870 60 87202.

There are other suppliers of similar software in the market. Please consult your supply directories or contact the EEBPP who may be able to provide you with more details.

NPCS 128, this version published 02/02

BACKGROUND

Aerial view of CPL

The vast quantities of process data available within SCADA systems can be very difficult to interpret, not least because of its volume, but also because the interaction between variables can be extremely complex, resulting in missed opportunities to improve performance. Data mining software offers a low-cost means of analysing and extracting useful information from such databases.

Data mining refers to a range of advanced techniques that have been developed to extract hidden knowledge from data. These techniques are widely applied in the financial, insurance and marketing sectors but are only just beginning to be used in the process industries. Data mining can be broadly divided into the following categories.

- Manual identification - where a pattern in the data is suspected in advance and database queries are used to confirm or otherwise that the pattern exists.
- Semi-automatic identification - where plots of parameters are generated in the hope that a pattern may be visually identified.
- Automatic identification - where patterns in the data are identified with only a limited amount of user input once an objective is established. The main technique used is rule induction, which involves identifying patterns and expressing them in an understandable form i.e. as rules. These rules are displayed graphically as a decision tree.

The last of these involving rule induction was central to this project, as it allowed the automatic identification of patterns in data, no matter how subtle or counter-intuitive, which is not possible with manual or semi-automatic techniques.

RULE INDUCTION

RULE INDUCTION

- The process of rule induction is carried out by repeatedly (recursively) splitting the given data set into two, according to different influencing factors (attributes) until terminal points (leaves) are reached, this is generally referred to as an outcome.

- The order by which the attributes are used in the decision tree depends on a measure of the classification power of each attribute. This two-way splitting is carried out to minimise the disorder in the resulting data sets at each split and hence it groups data that contains patterns. The route to the outcome describes the criteria for that rule.

- A forward pruning (cease branching) criteria is used to determine when terminal points are reached. This ensures that any patterns discovered are of significance and to some extent takes account of 'noise' in the data.

- The induction algorithm is binary in that it creates a two-way branch at every split in the tree.

The rule induction approach to modelling data has a number of advantages over other methods:

- models can be generated in seconds from large quantities of data;

- the models are transparent and can therefore be validated;

- the validity of each individual rule can be established.

UNDERTAKING A DATA MINING STUDY

The implementation of a data mining study involves the following steps:

- acquiring relevant data from process monitoring and control system;

- pre-processing data to remove irrelevant periods of data such as downtime;

- analysing data using both conventional and data mining techniques;

- developing decision tree model (rule induction);

- Implementing improved operating procedures or control systems based on data mining results.

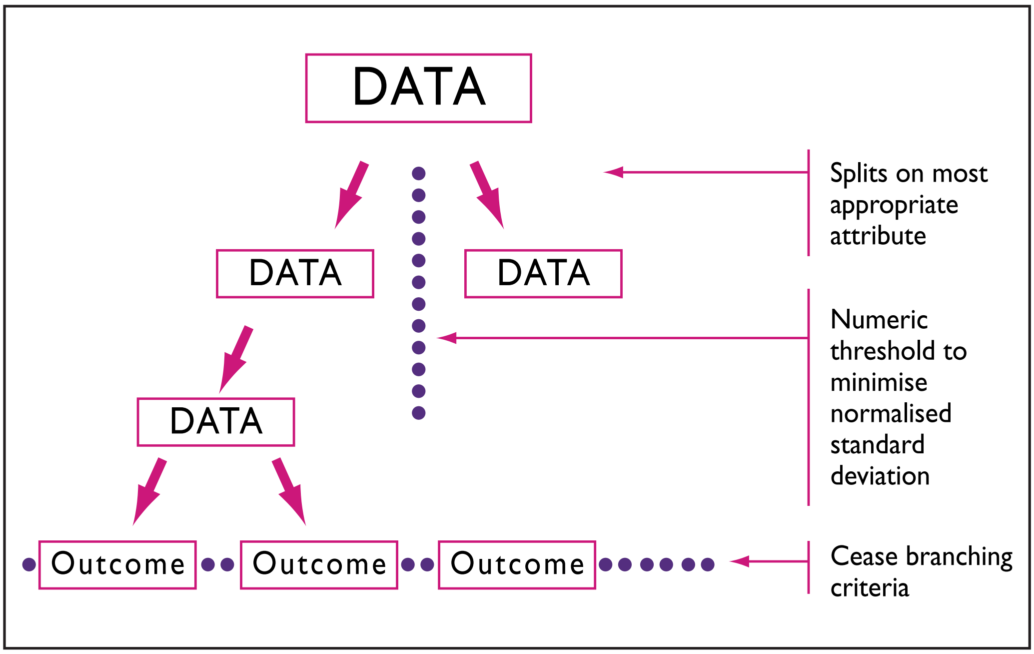


Fig 2 - Rule induction (two way splitting)

NPCS 128, this version published 02/02

POTASH DRYING

An initial scoping study was carried out to determine those areas of the mining and above-ground process operations that were likely to benefit from the application of data mining. These included underground operations, flotation, drying, compaction and milling. It was decided to focus on one of the rotary kiln dryers (B Dryer) for this first application of data mining at CPL.

Previous studies had indicated that improving the control performance of the dryers would produce benefits in terms of fuel savings, extended plant life, reduced emissions to atmosphere, improved reliability and more consistent product quality. Other considerations were the availability of operating data for the dryer from the SCADA system and that any benefits realised on B Dryer could probably be replicated on the other dryers.

POTASH DRYING

There are three rotary kiln dryers at CPL. Dryers A and B can each handle 60 tonnes/h of wet product (6% by weight moisture) from the flotation cells. Dryer C is smaller, taking 20 tonnes/h from the crystallisation plant and producing a higher-grade product. The purpose of these dryers is to dry the product by completely vaporising the water content, which varies with feed consistency and centrifuge efficiency.

The shell of Dryer B is 3 metres in diameter and 20 metres long, and rotates at 8 rpm. At the front (feed end) of the dryer is a refractory lined cylindrical combustion chamber that does not rotate with the dryer shell. The combustion chamber has a rotary cup fuel oil burner, and a forced draught fan supplies the burner with primary and secondary combustion air. The correct air-to-fuel ratio is controlled by dampers in the air ducts which are mechanically linked to the oil valve positioner.

Rotary kiln dryer

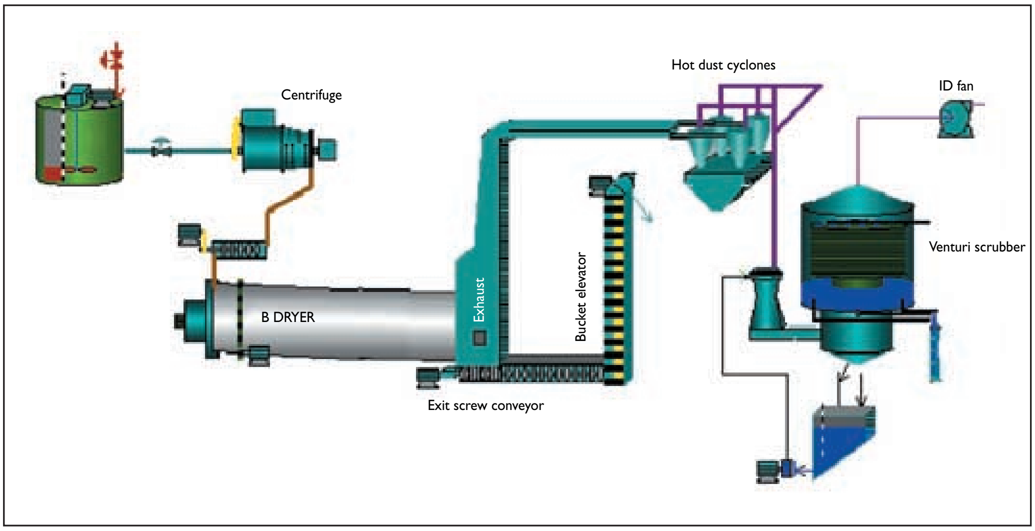


Fig 3 - Potash dryer layout

OPERATING DATA

A second fan provides dilution air part way along the combustion chamber. This prevents overheating of the refractory lining and excessive local temperatures, which would cause sintering of the product. This dilution air reduces the temperature of the combustion products to below 1,000°C. The flow is also regulated by the firing-rate.

The oil firing-rate controller, which has proportional and integral (PI) actions maintains the exhaust gas temperature set point. This set point is manually adjusted to achieve an adequate product temperature for the downstream compaction process and is generally well in excess of that required to vaporise all the moisture.

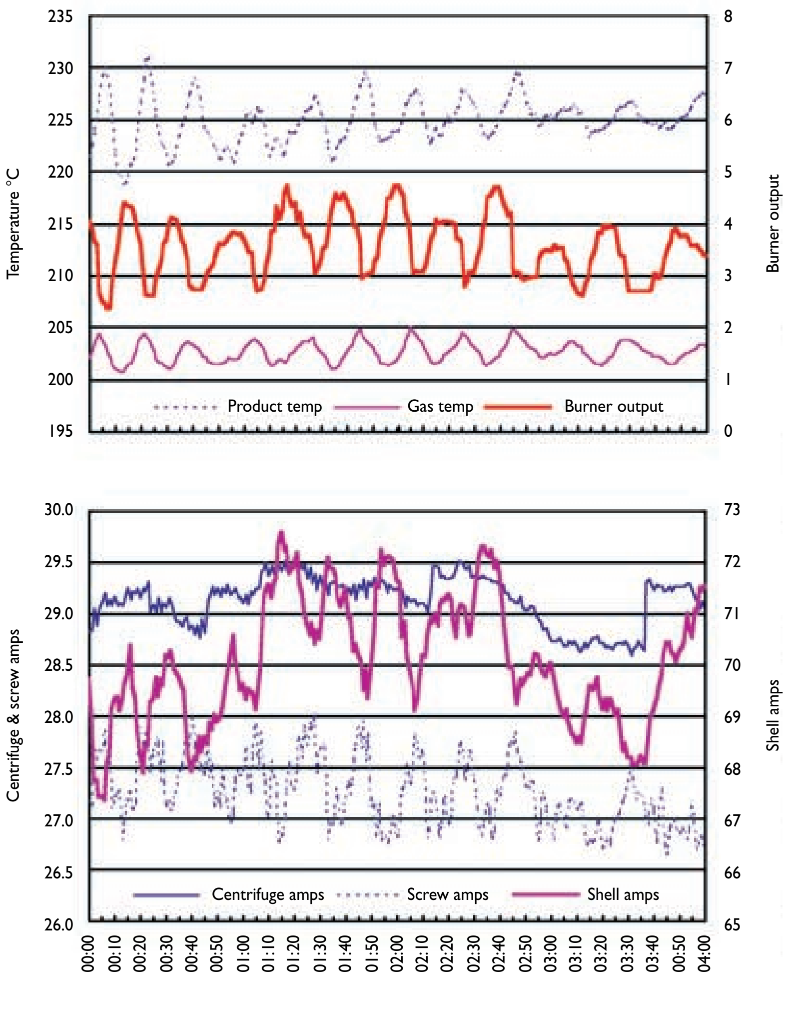
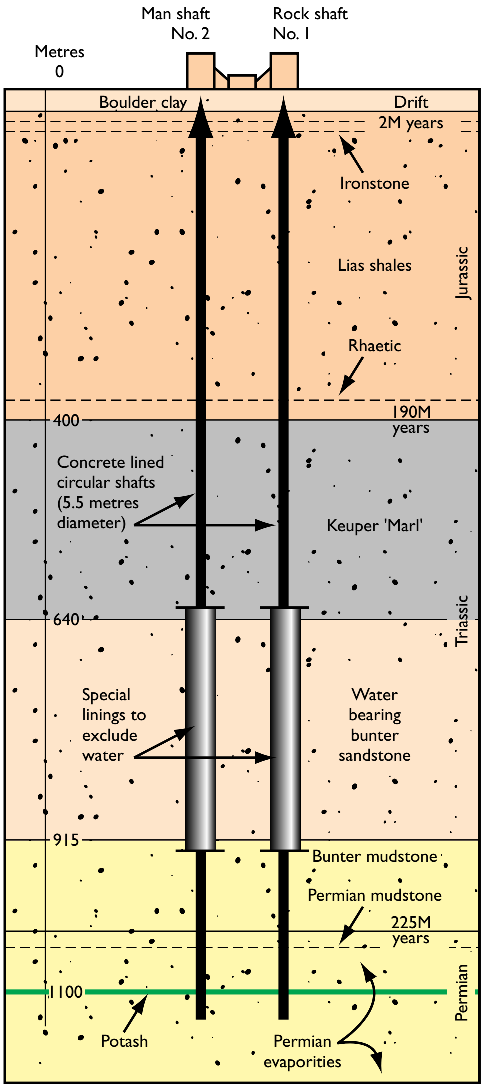


Fig 4 - B dryer measured variables - steady conditions, 1 November 1998



Schematic of underground soil composition

OPERATING DATA

Plant data was collected covering the period from November 1998 to February 1999, producing some 56,000 records over 900 hours of typical operation. Data collected included:

- exit product temperature;
- exit gas temperature;
- oil firing position - indicative of energy use;

DATA MINING ANALYSIS

- centrifuge current - indicative of product load and moisture content to the dryer;
- exit screw conveyor current - indicative of the quantity of dry product leaving the dryer;
- dryer shell current - indicative of product load in dryer.

Initial examination of the dryer data revealed the following trends and conclusions:

- short and long term variations in product temperature increasing energy use;
- the existing gas temperature controller was poorly tuned;
- improving control of product temperature will increase efficiency;
- the product temperature target threshold was established at 180°C.

DATA MINING ANALYSIS

Decision trees were generated to improve the understanding of the data. These used outcomes such as dryer oil firing rate, product temperature and dryer exhaust gas temperature and included all other parameters as attributes.

This gave a series of results and associations including:

- throughput is closely rated to oil rate;
- increasing the exhaust gas temperature set point increases oil firing;
- increased exhaust gas temperature set point correlates to increased product temperature.

The issues above could have been identified through conventional theoretical methods, however the more subtle issues revealed included:

- the effect of centrifuge operation on dryer stability;

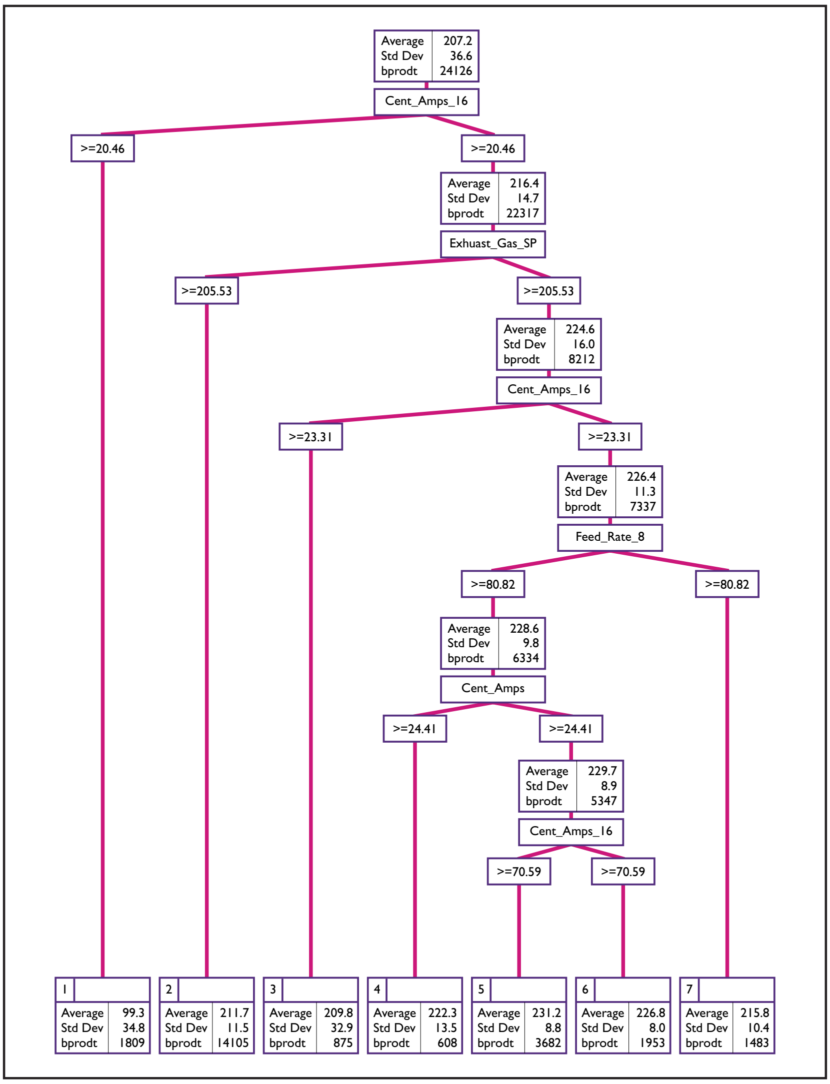


Fig 5 - Product temperature (outcome) decision tree

- the impact of dryer stability on energy use;
- the effect of high moisture levels on product temperature at high feed rates.

It was clear from the above that improving the control of the dryer product exit temperature would not only lead to a more energy efficient operation of the dyer, but it would permit a reduction in the target exit temperature leading to further fuel savings. The next step was to develop a predictive model for product temperature using rule induction.

MODELLING USING RULE INDUCTION

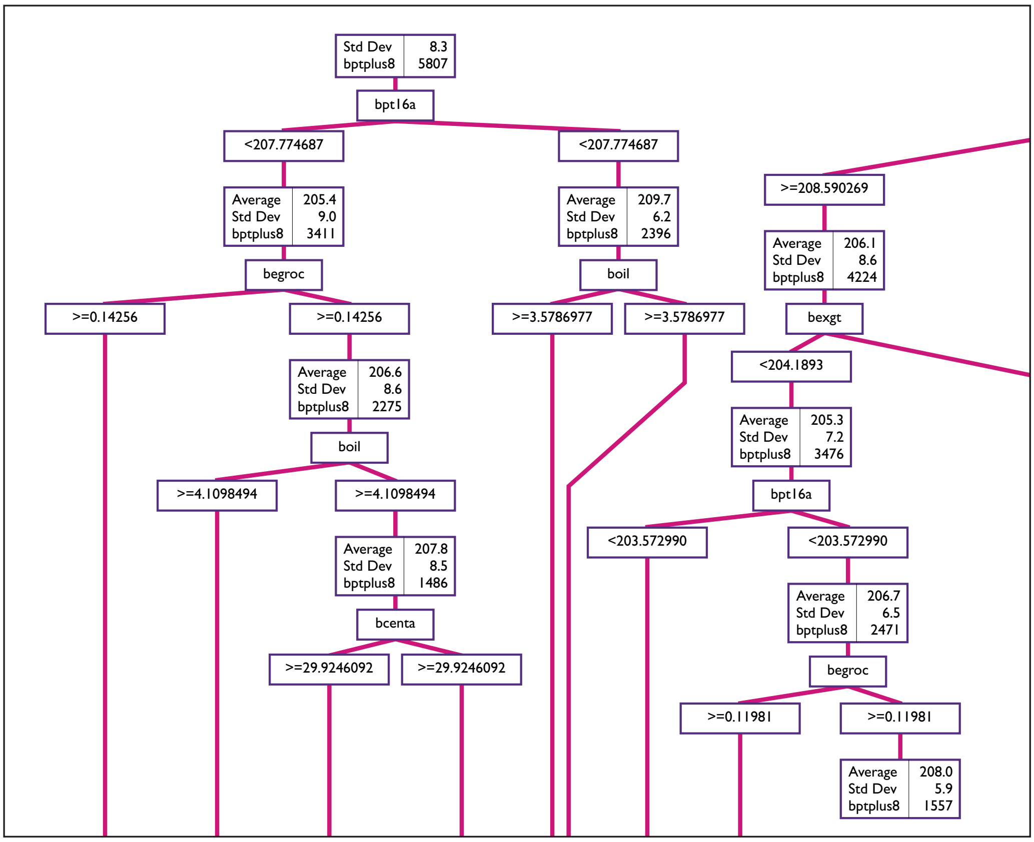
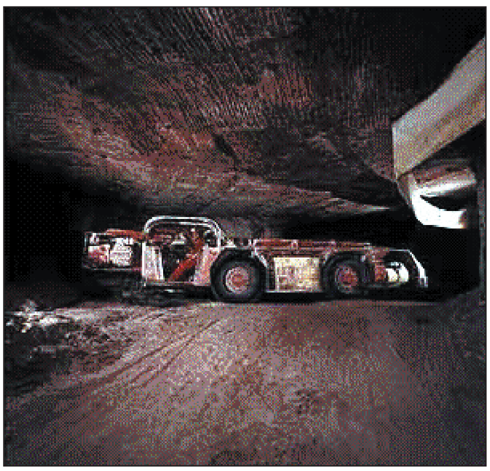


Fig 6 - Part of decision tree for eight-minute temperature prediction



Underground operations

MODELLING USING RULE INDUCTION

The data was randomly split into two databases, 'training' and 'test', and an 88 rule model was developed from the 'training' data with the outcome being defined as product temperature at a set time (8 minutes) in the future. The model predicts the future product temperature based on current and past product temperature and also other influencing factors including oil rate and other variables.

The validity of the model was established by comparing its prediction with the unseen 'test' data set previously removed from the original data. The fit of the model produced is characterised by a root mean square deviation of 2.8% for operations that are well represented by the training data.

RESULTS AND CONCLUSIONS

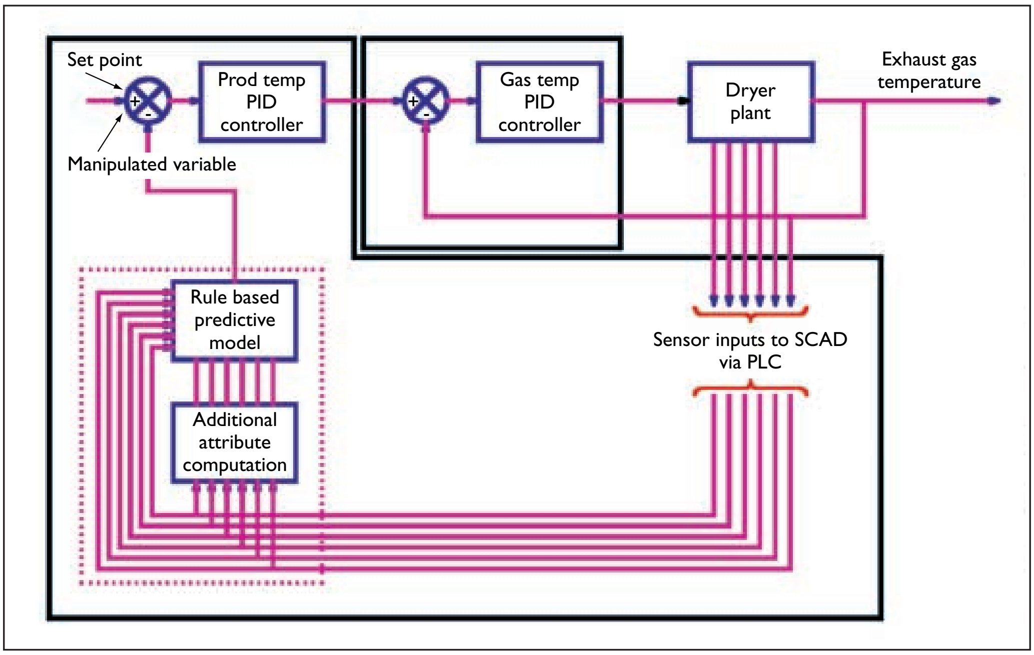


Fig 7 - Product temperature control scheme

Following the successful development of the predictive model for product temperature a new product temperature control scheme was implemented using the exiting exhaust gas temperature controller and the SCADA/PLC system.

The output from the predictive model was used as an input to a PID controller that provides a set point trim for the existing exhaust gas temperature controller. Advantages of this approach are that the new system can easily be adapted to accommodate additional knowledge in the future without compromising functionality, and it is easy to revert to the existing control strategy in the event of a failure of the advanced control system.

RESULTS OF DATA MINING PROJECT

Dryer Control System

Dryer product temperature control has been significantly improved following implementation of the rule based predictive cascade control system in April 1999. The following improvements were realised:

- the standard deviation of product temperature was reduced from 15 to 2.3;
- average product temperature was reduced from 216.5°C to 185°C;
- fuel cost saving of £47,000 a year for Dryer B.

The new control system can easily be incorporated onto dryers A and C, which should lead to net savings in the region of £110,000 per year.

Further Opportunities

The study gave CPL a greater understanding of the influence of feed moisture content on dryer energy requirements. This led to the identification of the additional energy saving opportunities that would result from the optimal washing of the centrifuges upstream of the dryers to achieve minimal feedstock moisture content. Another outcome is that it is now planned to evaluate instrumentation for the continuous on-line measurement of feed moisture content.

COSTS AND BENEFITS

The study also helped identify that improved dryer draught control would be obtained by fitting a variable speed drive to the induced draught fan. This would realise electricity cost savings of £24,000/year on each of the two largest dryers.

Skills Transfer

Throughout the project CPL had the input of a consultant who is an experienced data mining practitioner whose role was to provide technical leadership and training in the use of data mining techniques and the software. As a result of this approach CPL now have in-house expertise and a structured approach to data mining that can be used for future work.

COSTS AND BENEFITS

The work involved in the dryer study was approximately 30 man-days, costing some £15,000, plus £5,000 for hardware and software. The fuel cost savings on B Dryer alone gave a payback in under six-months.

- This project has demonstrated the ability and ease with which data mining tools can analyse large quantities of data and reveal relationships and interactions that may not always be apparent from more conventional study of a complex process operation. This may increase the understanding of that process and reveal new opportunities for improvement.

- It has been demonstrated that rule induction can be used in modelling for control purposes, for example to produce a predictive control model. Such rule-based models can easily be implemented on modern SCADA/PLC systems without the need for additional software, yielding energy savings or other process benefits that result in added value.

- The development of a structured approach to the analysis of archived operating data is a valuable asset. Data mining studies may be used to identify and justify to management low cost, rapid payback, projects that might otherwise not be implemented or even recognised.

- Data mining provides a cost-effective strategy that can be widely applied at CPL and elsewhere on many process or control applications where large quantities of historical data are available. It is a tool that can be applied within the process industries to complement the more conventional expertise of the process engineer.

The Government's Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. The information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

For further information visit our web site at www. energy-efficiency.gov.uk or

for buildings-related topics please contact:

BRECSU
Building Research Establishment
Garston, Watford, WD2 7JR
Tel: 01923 664258
Fax: 01923 664787
E-mail: brecsuenq@bre.co.uk

for industrial and transport topics please contact:

ETSU
Harwell, Didcot, Oxfordshire,
OX11 0QJ
Fax: 01235 433066
Helpline Tel: 0800 585794
Helpline E-mail: etbppenvhelp@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.